Evaluation of Electronic Temperature/Relative Humidity Sensors[1]

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Abstract

Temperature and relative humidity measurements are routine parameters required for most agricultural meterological applications. Reliable measurements of relative humidity, especially at remotely located weather stations, are extremely difficult to obtain. This study was undertaken to evaluate a number of commercial temperature/relative humidity sensors in the Southern High Plains environment for use in automated weather stations.

Introduction

Measurement of temperature and relative humidity (RH) is vital for estimation of evapotranspiration. Numerous methods are available to measure and record moisture in the air but all are subject to many possible errors.

During the 1500's, devices used for humidity measurements were based on mechanical changes of natural materials such as wool, wood, paper and hair. The response of these materials changed as they aged and the effects of temperature were generally ignored in the calibration. The psychrometer, developed in 1792, is more accurate but subject to errors from the manual reading of the thermometers, contaminated water, dirty wicks, and other human errors (Hannon, 1984).

Recent developments of electronic instruments using varied materials that change resistance or capacitance have improved the ability to measure RH. The instruments usually include a temperature measurement and often use the temperature to calculate or correct RH sensor output. These sensors can drift and degrade over time in the environment (Brown et al., 1989). The specifications of the various electronic sensors often indicate limitations at both high and low humidities. For meteorological uses, where humidity ranges from 100% to less than 10%, this limitation plus the pollutants and dust of the atmosphere limit the use of many types of RH instruments.

A weather station was established at the USDA-ARS Conservation and Production Research Laboratory, Bushland TX, in late 1987 in conjunction with four large weighing lysimeters. The station is equipped to measure wind speed, temperature, and wind direction on a meterological tower; dew point temperature,

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barometric pressure, air temperature and relative humidity are measured in a standard National Weather Service 'cotton-belt' shelter. Pan evaporation, precipitation, and incoming and diffuse radiation components are also measured at the station. The weather station is located adjacent to the lysimeter fields and is maintained over a cool-season, irrigated grass. The outputs of the sensors are measured and recorded by a Campbell CR7X data logger[3] with daily downloads by a computer via telephone modem. The different parameters at the weather station are measured every 6 seconds and either averaged or summed to 15 minute outputs and processed to a final output for hardcopy distribution as 30 minute summaries for the day.

Data from this weather station are routinely used for evapotranspiration research projects. The accuracy of the data is very important to the research projects needing climatic data from this site. Many quality checks are made during data processing. This paper documents some of the difficulties we have encountered in obtaining accurate temperature and relative humidity data from the different instruments.

Temperature and Humidity Instrumentation

The chronology of the sensors, manufacturer, and sensor electronics in the station are presented in Table 1. As instruments in the natural environment developed problems, secondary methods were needed to readily detect and monitor data quality. The dew cell electronics failed in 1990, and this sensor was not replaced until 1991.

Table 1. Chronology of Instrumentation for the Weather Station.

Date	Sensor Mfg.	Sensor
1987	Campbell 207 YSI Dew Sensor	Phys-Chem PCRC-11 RH sensor, Fenwal UUT51-J1 Thermistor YSI 9400 Li-Cl dew cell
1989	Psychrometer	Local construction, (Lourence and Pruitt, 1969) Cu-Co thermocouples (Omega 30455)
1990	Campbell XN217	Hygrometrix hydro-mechanical stress RH sensor, Fenwal thermistor
1991	Rotronic MP100 Campbell HMP35C R M Young 41407	Polymer foil capacitor, 100 ohm platinum resistor Vaisala capacitive polymer RH chip, Fenwal thermistor YSI 9103 Li-Cl dew cell

Problems Encountered

The data processing programs compare the output of the sensors against limits of reliability where applicable. In the instance of temperature and RH data, all instruments are compared with the output of the others in determining a final output. Every 10 days, the data are graphed for a visual observation of the data

[3]Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U.S. Department of Agriculture, nor does it imply registration under FIFRA as amended.

as another error check. The 10-day graphical outputs compare dew point calculations from the various instruments as well as RH and temperature.

We experienced several problems with the Campbell 207 temperature-humidity sensor. The Phys-Chem chip is subject to degradation when exposed to the atmosphere. Replacement of the RH chip is recommended at least every six months (users manual). The sensor electronics were also affected by the environment as small spiders could enter the bottom of the sensor and build webs which would short the thermistor when humidity neared 100%. This problem was eliminated by sealing the electronics in silicon and has not been a problem since. Campbell Scientific has since redesigned the electronics casing in response to this problem.

The dew point probes we used are AC-powered, bifilar gold electrodes wound on a Li-Cl impregnated wick which contain a thermistor temperature sensor. The original probe from YSI and the second from R. M. Young, both contain virtually the same dew cell manufactured by YSI. The primary difference in the two is the electronic packaging. The electronics of the original YSI dew cell failed, probably because of an electrical spike during a thunderstorm. Difficulties in having the package repaired led to the purchase of another sensor. Both probes were subject to errors as the contaminants increased until the wicks had to be cleaned and reimpregnated with the lithium chloride solution. The windings are quite fragile and regular cleanings of the delicate instrument are tedious but necessary to maintain the sensors at their maximum performance. Also, the dew cells can not measure RH below 13%, the equilibrium RH for Li-Cl. To calculate RH from the dew point temperature, we calculate the saturation vapor pressure (SVP)(Murray, 1967) of the dew point and psychrometer dry bulb and then calculate RH as:

$$RH = 100 * SVP(dew) / SVP(dry)$$

The addition of the psychrometer solved as well as created problems. Various ethyl alcohol-water mixtures were tried during the winter to lower the freezing point for the wet bulb. We found that during warmer periods, the alcohol mixture would evaporate faster than water and thus lower the wet bulb temperatures and decrease RH calculations. Since then, we have simply eliminated the psychrometer data when the wet bulb temperatures are at or below freezing. Determining when ice has liquified after a period of freezing temperature is still a problem for the computer programs.

The XN217 was added to give us another 'cold weather' check of RH. The sensor performed very well for a period of time. It was noted that spiders could get into the RH sensor, and then the web would retain moisture beyond when other sensors indicated lower humidities. The sensor is quite durable and can be washed and softly brushed which helped for a period of time. Also the sensor frequently produces humidity readings greater then 100 percent. The sensor was recalibrated in 1992 and some data after recalibration were used for this paper to indicate the accuracy of a factory recalibration.

The Rotronic MP-100 sensor has a very fine filter (special order) which has performed well at keeping spiders and dust from the sensor. The sensor has been in use for nearly two years without a failure (except for AC-power outage). We have obtained sensors which can be excited by DC-voltages for other projects, although a DC-powered sensor has not yet been installed in the weather station for comparisons.

The Campbell HMP35-C is a part of a self-contained Campbell 012 weather station being used at a site about 800 m from the weather station. The sensor is being used only during periods of the summer growing season, and the data from it were added for this paper. We experienced no problems with the sensor, but more time in the field is needed for a full evaluation.

Data Analysis

We used several two-day periods to compare the various RH and temperature sensors. We selected data with as wide a range of RH and temperature as possible at approximate 50-day intervals. Since we were using the psychrometer data to compare to the other sensors, finding periods early and late in the year where temperatures were above freezing was important. The data from each 2-day period were analyzed using linear regressions to compare RH and temperature from the different sensors to those obtained using the psychrometer. A series of regressions for each 2-day period over time Satisfactory performance is indicated by slopes near 1, intercepts near 0, and high r^2 values.

RH Results

Graphical displays and regression analysis of RH used in this section are based on data collected during relatively warm periods (no freezing of the wet bulb of the psychrometer) for 1000 consecutive hours (approximately 40 days). Temperature graphics and analysis are from similar time periods but were not limited by freezing temperatures.

The slopes for the 207 indicate the Phys-Chem sensor to be quite reliable for a time but it is difficult to predict when it might start giving erroneous data. Note the late 1989 and early 1990 data (Table 2). Replacement of the sensor chip after 6 months in the field is quick and easy but a new chip will not necessarily read the same RH as the chip being replaced since specifications are ± 2% RH. The specifications of the 207 note a high probability of error above 90% RH and below 20% RH which we observed when comparing the 207 RH to the psychrometer RH (Fig 1).

The dew cell sensors exhibited problems with accuracy indicated by low regression slopes (Fig. 2). The linearity of the dew sensors as compared to the psychrometer RH were otherwise very good (Table 2). As is the case of some other instruments, limitations of high and low RH values would make this type of

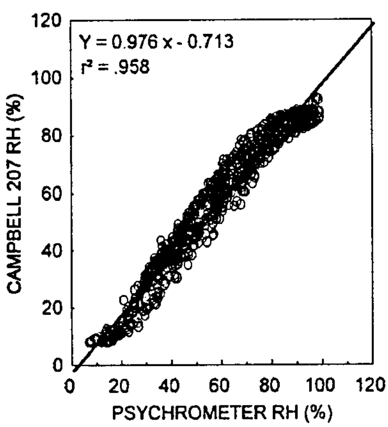

Figure 2. A comparison of the 207 RH output related to the psychrometer RH showing problems at high and low values.

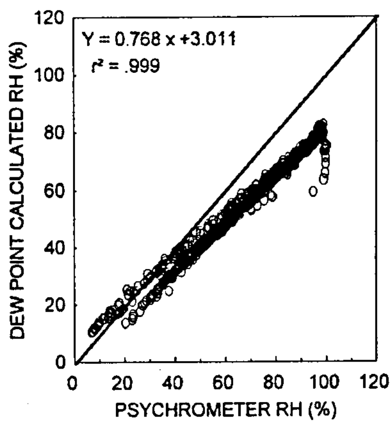

Figure 1. RH calculated from the dew point indicating problems with accuracy of RH as compared to the RH of the psychrometer.

Table 2. Linear regression coefficients for hourly RH measured with various sensors (Y) compared to the RH calculated (X) using the wet and dry bulb temperature of the psychrometer.

	207			Dewpoint			XN217			Rotronic			HMP35-C		
yr day	slope	int	r^2	slope	int	r^2	slope	int	r^2	slope	int	r^2	slope	int	r^2
89 151	1.18	-11.89	0.97	0.88	5.90	0.99									
89 198	0.99	4.03	0.97	0.85	5.99	0.99									
89 250	0.94	6.63	0.98	0.82	7.11	0.99									
89 298	0.99	-0.70	0.96	0.85	3.97	0.99									
89 344	0.90	11.16	0.98	0.89	13.98	0.99									
90 007	0.77	7.18	0.93	0.93	10.38	0.97									
90 047	0.99	-1.18	0.96	0.87	10.21	0.99									
90 098	0.96	8.15	0.98	0.83	8.55	0.99									
90 149	1.06	-0.31	0.97	0.91	4.45	0.96									
90 198	1.03	3.42	0.96	0.81	8.31	0.99	1.01	2.78	0.98						
90 248	1.07	-2.36	0.98	0.77	9.48	0.99	1.05	0.72	0.99						
90 290	1.09	-7.95	0.97				0.92	6.66	0.97						
90 345	RH CHIP			ELECTRONICS			1.06	-3.44	0.98						
91 014	ON ORDER			FAILED			0.83	9.29	0.86						
91 056	1.13	-9.81	0.95				0.99	4.46	0.98						
91 102	1.06	-4.01	0.96				1.03	1.97	0.97						
91 149	1.03	1.52	0.97				0.77	25.39	0.99						
91 198	1.17	-7.10	0.97				0.72	21.60	0.98						
91 246	0.82	17.58	0.96	0.82	4.81	0.99	0.74	24.33	0.99						
91 302	1.01	2.34	0.97	0.74	7.83	0.99	0.66	35.74	0.98	0.96	4.13	0.99	0.97	5.22	0.92
91 355	0.98	3.91	0.95	0.77	5.59	0.99	0.88	17.40	0.96	0.98	1.88	0.99			
92 010	0.98	4.14	0.91	0.70	9.45	0.92	0.65	27.49	0.91	0.89	7.24	0.92			
92 043	1.02	2.79	0.96	0.72	10.10	0.99	0.58	41.06	0.98	0.95	6.76	0.99			
92 099	1.04	-4.42	0.96	0.77	3.65	0.99	0.67	34.90	0.98	1.02	-0.49	0.99			
92 148	0.86	6.21	0.95	0.82	-0.69	0.99	0.64	39.47	0.98	1.04	-3.68	0.99			
92 199	0.80	11.96	0.96	0.79	6.77	0.99	0.43	56.11	0.98	0.92	7.53	0.99	0.95	6.21	0.98
92 250	1.11	-10.78	0.97	0.81	2.73	0.99	RECALIBRATION			1.06	-3.28	0.99	1.03	1.16	0.99
92 300	0.94	8.85	0.96	0.81	2.28	0.99	PERIOD			1.00	-0.31	0.99			
92 342	0.95	7.34	0.97	0.76	8.10	0.99	1.01	3.78	0.98	0.99	1.88	0.99			

instrument questionable for many environments.

The XN217 showed a drift over time (Table 2). Sensor output remained quite linear, even after the slope and intercept became unacceptable. Cleaning the sensor did not cure the problem and factory recalibration became necessary. Since we have only one sensor, these data may not be a true representation of this instrument, especially since it produced very good data for almost a year. After recalibration, the XN217 data compared well with the psychrometer. In all cases, at least yearly recalibration and a backup instrument are definitely justified.

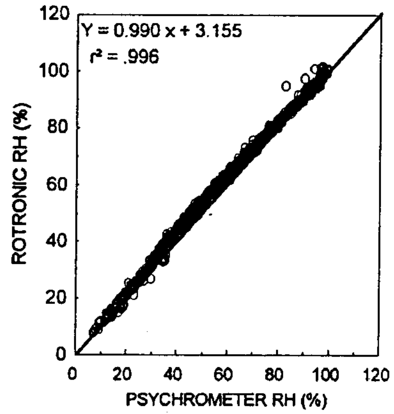

Figure 3. A comparison of the Rotronic RH related to the psychrometer indicating a close 1:1 fit.

The Rotronic MP-100 sensor has been excellent to date (Fig 3). The slope, intercept and r^2 values as related to the psychrometer are as good as can be expected in a field environment and there are no biases at either high or low RH.

Data from the Campbell HMP35-C were compared with the sensors from the weather station and found to relate quite well (table 2) even with the distance between the sensors. Personal communications with Campbell Scientific indicate the RH sensor to be reliable in a field environment but further evaluation is needed.

<u>Temperature Results</u>

Accuracy of temperature measurement has not been a problem with any

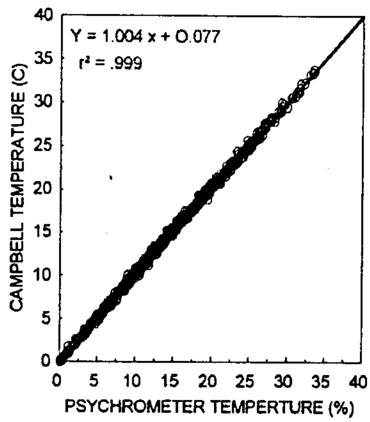

Figure 4. The 207 temperature as related to the dry bulb of the psychrometer indicating a very close 1:1 fit.

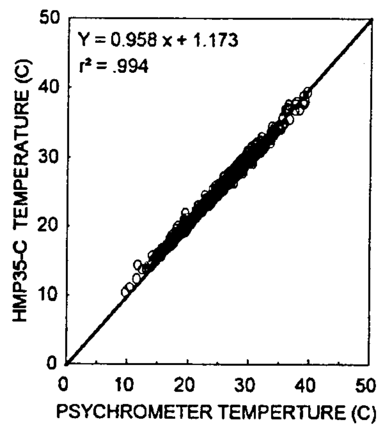

Figure 5. A comparison of the HMP35-C temperature indicating some scatter from the 1:1 line due to the remote location.

of the sensors. Since the early experiences with the spider web problem in the electronics of the Campbell 207 thermistor, we have had excellent correlations from all temperature probes as shown in Fig. 4 comparing the 207 probe temperature to the psychrometer dry bulb. Based on 1000 consecutive hours of data, the Rotronic (.999) and Campbell 207 (.999) thermistors have the greater r^2 values followed by the XN217 (.997).

Although the Campbell HMP35-C was located some distance from the weather station and in a slightly different environment than the irrigated grass, the temperatures compared favorably with the psychrometer (Fig 5).

Conclusions

The use of only one sensor of each type is not a viable test of the instruments. All the instruments used measure temperature very well. Of the six RH sensors named in this paper, only the dew point sensor is probably unacceptable for use in the field environment. Outputs from each of the instruments gave RH values which were linearly related to the psychrometer RH calculation. Most of the sensors have either replaceable RH sensors or can be cleaned to rejuvenate the sensor. In all cases, a single instrument cannot be the sole source of data and backup instruments are necessary.

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